Prepared in cooperation with the U.S Agency for International Development

Fifty-Year Storm-Tide Flood-Inundation Maps for Santa Rosa de Aguán, Honduras

U.S. Geological Survey Open-File Report 02-258

U.S. Department of the Interior
U.S. Geological Survey

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By Mark C. Mastin and Theresa D. Olsen

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 02-258

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CONVERSION FACTORS

Multiply	By	To obtain
cubic meter per second (m^3/s)	35.31	cubic foot per second
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
millimeter (mm)	0.03937	inch
square kilometer (km^2)	0.3861	square mile

VERTICAL DATUM

Elevation: In this report "elevation" refers to the height, in meters, above the ellipsoid defined by the World Geodetic System of 1984 (WGS 84).

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ABSTRACT

After the devastating floods caused by Hurricane Mitch in 1998, maps of the areas and depths of the 50-year-flood inundation at 15 municipalities in Honduras were prepared as a tool for agencies involved in reconstruction and planning. This report, which is one in a series of 15, presents maps of areas in the coastal municipality of Santa Rosa de Aguán that are prone to oceanic storm-surge flooding and wave action. The 50-year flood on the Río Aguán (4,270 cubic meters per second), would inundate most of the area surveyed for this municipality and beyond. Therefore a detailed numerical hydraulic model was not developed for this municipality as it was for the others. The 50-year storm surge would likely produce higher water levels than the 50-year flood on the river during normal astronomical tides. The elevation of the 50-year storm surge was estimated to be 4.35 meters above normal sea level, based on hurricane probabilities and published storm-surge elevations associated with various hurricane categories. Flood-inundation maps, including areas of wave-action hazard and a color-shaded elevation map, were created from the available data and the estimated 50-year storm tide.

Geographic information system (GIS) coverages of the hazard areas are available on a computer in the municipality of Santa Rosa de Aguán as part of the Municipal GIS project and on the Internet at the Flood Hazard Mapping Data Web page (http://mitchnts1.cr.usgs.gov/projects/floodhazard.html). These coverages allow users to view the maps in much more detail than is possible using the maps in this report.

INTRODUCTION

In late October 1998, Hurricane Mitch struck the mainland of Honduras, triggering destructive landslides, flooding, and other associated disasters that overwhelmed the country’s resources and ability to quickly rebuild itself. The hurricane produced more than 450 millimeters (mm) of rain in 24 hours in parts of Honduras and caused significant flooding along most rivers in the country. A hurricane of this intensity is a rare event, and Hurricane Mitch is listed as the most deadly hurricane in the Western Hemisphere since the “Great Hurricane” of 1780. However, other destructive hurricanes have hit Honduras in recent history. For example, Hurricane Fifi hit Honduras in September 1974, causing 8,000 deaths (Rappaport and Fernandez-Partagas, 1997). Hurricane Mitch made landfall on October 29 at Santa Rosa de Aguán as a Category 1 hurricane (U.S. Geological Survey, 2000).

As part of a relief effort in Central America, the U.S. Agency for International Development (USAID), with help from the U.S. Geological Survey (USGS), developed a program to aid Central America in rebuilding itself. A top priority identified by USAID was the need for reliable maps of areas of flood hazard in Honduras to help plan the rebuilding of housing and infrastructure. The Water Resources Division of the USGS in Washington State, in coordination with the International Water Resources Branch of the USGS, was given the task to develop flood-hazard maps for 15 municipalities in Honduras: Catacamas, Choloma, Choluteca, Comayagua, El Progreso, Juticalpa, La Ceiba, La Lima, Nacaome, Olanchito, Santa Rosa de Aguán, Siguatepeque, Sonaguera, Tegucigalpa, and Tocoa. This report presents flood- and wave-hazard maps of areas in the municipality of Santa Rosa de Aguán that are prone to oceanic storm-surge flooding and wave action.

The original intent of the study was to delineate the area that would be inundated by the 50-year-flood discharge of the river. The 50-year flood is one that has a 2-percent chance of being equaled or exceeded in any one year and on average would be equaled or exceeded once every 50 years. The 50-year flood, however, would inundate an area well beyond the area surveyed for this project. Also, much of the study area is sandy deltaic deposits from the Río Aguán that shift frequently with the changing course of the river; therefore, the numerical model chosen for this project, which assumes a relatively static channel and floodplain geometry, is not suited for the area. Consequently, flood hazard areas are delineated on the basis of the estimated 50-year storm-tide elevation, and wave hazard areas are delineated on the basis of the elevation and position relative to the beach.

Purpose, Scope, and Methods

This report provides (1) an estimate of the 50-year flood discharge, for the Río Aguán and Río Chapagua system, including some historical discharges for comparison, (2) an estimate of the elevation of the 50-year storm surge in the Caribbean Sea in the vicinity of Santa Rosa de Aguán, (3) a map delineating areas of flood hazard based on the 50-year storm tide for the municipality of Santa Rosa de Aguán and the surrounding area, and (4) a map delineating areas with a high-wave hazard.

The analytical methods used to estimate the 50-year-flood discharge, which relates discharge to drainage area and precipitation, are described in a companion report by Mastin (2002). These flood discharges are provided for the reader's information and are not used to define the flood hazards for Santa Rosa de Aguán, which are based on the estimated storm-surge elevation. Hazards due to waves are based on elevations and positions of the foundations of several houses near the beach that did or did not have substantial structural damage during Hurricane Mitch.

Because of the high cost of obtaining high-resolution elevation data, the extent of mapping was limited to areas of high population where flooding is expected to cause the worst damage. The findings in this report are based on the condition of the river channel and floodplains on March 11–12, 2000, when high-resolution light-detection-and-ranging (LIDAR) elevation data were collected, and on ground surveys of houses made in April 2000.

Land-surface elevation data were obtained from a high-resolution digital elevation model (DEM) created from a LIDAR survey verified with ground surveys. The LIDAR survey was conducted by personnel from the University of Texas. A fixed-wing aircraft with the LIDAR instrumentation and a precise global positioning system (GPS) flew over the study area on March 11-12, 2000. The relative accuracy of the LIDAR data was determined by comparing LIDAR elevations with GPS ground-surveyed elevations at 25 points in the Santa Rosa de Aguán study area. The mean difference between the two sets of elevations is 0.092 meter, and the standard deviation of the differences is 0.068 meter. The LIDAR data were filtered to remove vegetation while retaining the buildings to create a "bare earth" elevation representation of the floodplain. The LIDAR data were processed into a GIS (Arc/Info™) GRID raster coverage of elevations at a 1.5-meter cell resolution.

Acknowledgments

We acknowledge USAID for funding this project; Jeff Phillips of the USGS for providing data and field support while we were in-country; and Jim Gibeaut and Roberto Gutierrez of the Bureau of Economic Geology at the University of Texas at Austin for providing the data and comments related to the houses damaged by flooding and wave action.

DESCRIPTION OF STUDY AREA

The community of Santa Rosa de Aguán is situated on the Caribbean Sea at the mouth of Río Aguán (figure 1). Río Aguán flows from the south-southeast, splitting the residential area of the community into a left-bank area (looking downstream) and a right-bank area. The latter is accessible only by boat, with Río Aguán on its southwest side and the Caribbean Sea on its sandy north side (figure 1). Most of the study area consists of sandy deltaic deposits of Río Aguán. The propensity of the river to change course on its sandy delta was confirmed by Mr. Roberto Gutierrez during his three visits to Santa Rosa de Aguán between March 2000 and January 2001.

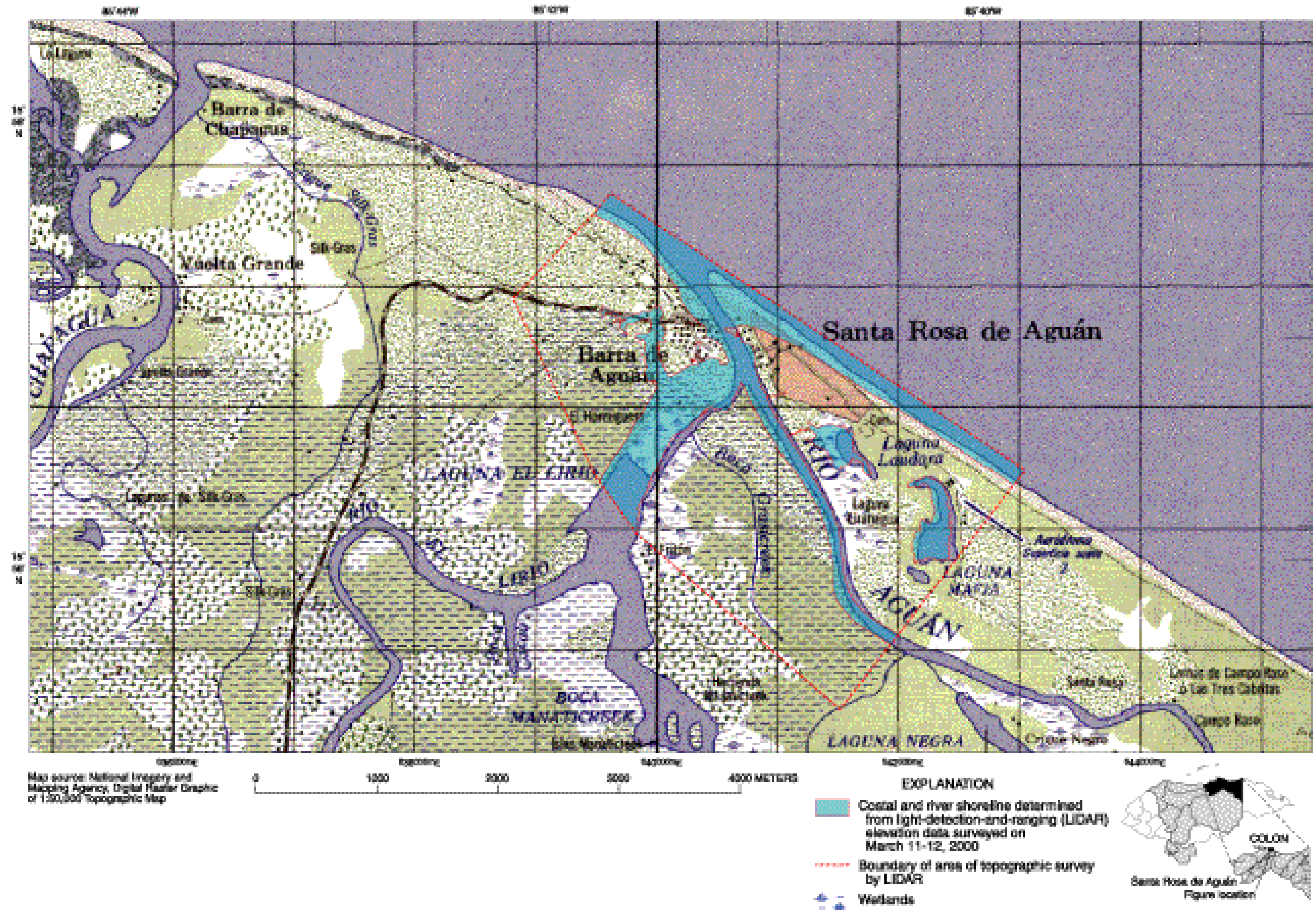

Figure 1. Location of study area and boundary of topographic survey at Santa Rosa de Aguán, Honduras.

During each of his visits, Mr. Gutierrez noted changes in the position of Río Aguán at the mouth and the size of the longitudinal sand bar between the river and the Caribbean Sea, which varied from not visible to something on the order of a kilometer or more in length (R. Gutierrez, University of Texas, oral commun., January 2001).

The slope of the river is fairly flat as it approaches the Caribbean Sea (the slope of the water-surface of the channel during the LIDAR survey was 0.00005) and there are many meanders and meander scars in its floodplain. Most of the community of Santa Rosa de Aguán lies within ground elevations between 1 and 5 meters. There were no high-water-mark data from the Hurricane Mitch flood, however one resident of Santa Rosa de Aguán described waking to flood waters at chest-high level in his home. Except for the residential area and the sandy beaches along the Caribbean, lagoons and wetlands are the predominate land cover (figure 1).

During high flows, some of the water from Río Aguán flows to Río Chapagua at Puente Durango, approximately 60 river kilometers (km) upstream from Santa Rosa de Aguán (figure 2). Río Chapagua flows into the Caribbean Sea approximately 5 km northwest of the mouth of Río Aguán.

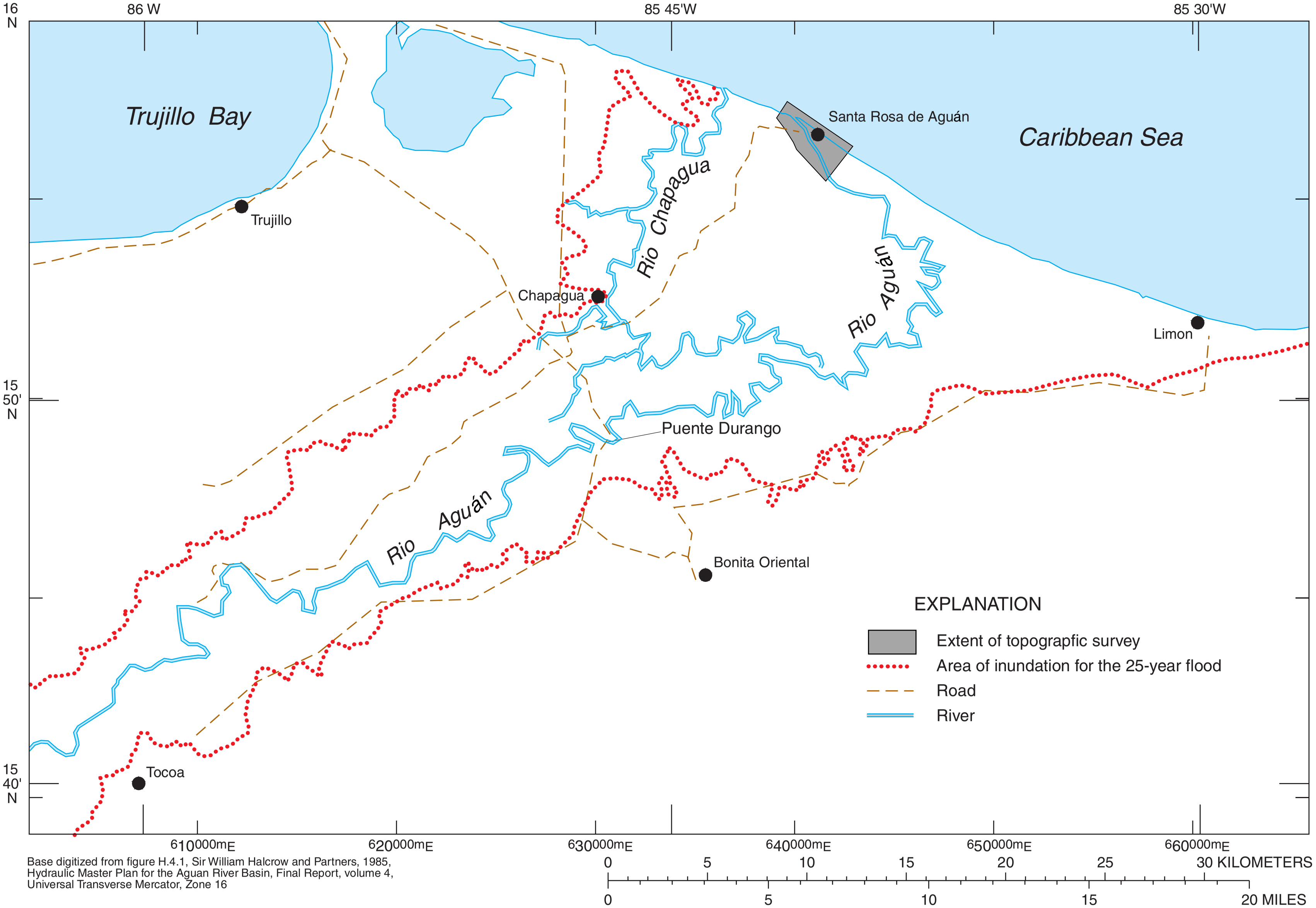

Figure 2. Extent of the airborne topographic survey at Santa Rosa de Aguán, Honduras, and the area of inundation for the 25-year flood from model simulations by Sir William Halcrow and Partners (1985).

FIFTY-YEAR FLOOD DISCHARGE

This section is divided into two subsections to describe flooding in terms of river discharge and flooding due to hurricanes and the associated storm tide. As described above, the construction of a hydraulic model to accurately estimate water-surface elevations of the 50-year flood could not be achieved with the available data. However, a simple model was constructed within the limited area of the topographic survey to assess the relative affect of the river flooding compared to the flooding caused by storm surge. The estimated 50-year flood discharge for the Río Aguán system is provided in the next section for informational purposes and not used in the development of the flood-hazard maps. The flood-hazard map presented in this report is based on the highest storm tide that would be expected to occur on average once every 50 years.

River Discharge

There are no long-term streamflow records for Río Aguán near Santa Rosa de Aguán. Therefore, the 50-year-flood discharge was estimated using the following regression equation, which was developed using data from 34 streamflow stations throughout Honduras with more than 10 years of annual peak flow record, that relates the 50-year peak flow with drainage basin area and mean annual precipitation (Mastin, 2002).

$$Q_{50} = 0.0788(DA)^{0.5664}(P)^{0.7693}\,, \qquad (1)$$

where

Q_{50} is the 50-year-flood discharge, in cubic meters per second (m^3/s),

DA is drainage area, in square kilometers (km^2), and

P is mean annual precipitation over the basin, in mm.

The standard error of estimate of equation 1, which is a measure of the scatter of data about the regression equation, is 0.260 log unit, or 65.6 percent. The standard error of prediction, which is a measure of how well the regression equation predicts the 50-year-flood discharge and includes the scatter of the data about the equation plus the error in the regression equation, equals 0.278 log unit, or 71.3 percent

The drainage area of Río Aguán at Santa Rosa de Aguán was determined to be 10,580 km^2 using a geographic information system (GIS) program to analyze a digital elevation model (DEM) with a 93-meter cell resolution obtained from the U.S. National Imagery and Mapping Agency (David Stewart, USGS, written commun., 1999). The mean annual precipitation over the Río Aguán drainage basin was determined to be 1,549 mm using a GIS program to analyze a digitized map of mean annual precipitation at a scale of 1:2,500,000 (Morales-Canales, 1997–1998, p. 15).

The 50-year-flood discharge estimated from equation 1 for Río Aguán at Santa Rosa de Aguán is 4,270 m^3/s. However, some of that discharge probably will flow into Río Chapagua. For example, the peak discharge during the 1974 Hurricane Fifi flood was estimated at 1,750 m^3/s at Puente Durango above the point where water flowed from Río Aguán to Río Chapagua (figure 2). Of the total flow of 1,750 m^3/s, an estimated 1,150 m^3/s flowed down the Rio Chapagua while only 600 m^3/s flowed down the lower Río Aguán (Sir William Halcrow and Partners, p. H.21, 1985).

For comparison, the peak-flood discharge due to Hurricane Mitch, estimated by a three-section, slope-area, indirect method, was 19,700 m^3/s at a site near Clifton (Mark Smith, U.S. Geological Survey, written commun., April 2001), which lies approximately 180 river kilometers upstream of Santa Rosa de Aguán and has a drainage area of 7,463 km^2. Using the regression equation developed to estimate the 50-year peak flow, the estimated 50-year peak flow for Río Aguan near Clifton is 3,270 m^3/s, or about one-sixth the discharge of the Hurricane Mitch peak flow. Sir William Halcrow and Partners (1985) estimated that the Hurricane Fifi flood approximates a 25-year flood event and mapped the extent of the flooding from model simulations in the lower Río Aguán (figure 2). The estimated 50-year peak flow of Río Aguán at Puente Durango is 3,980 m^3/s using the regression equation, which is about 2.3 times the estimate by Sir William Halcrow and Partners of 1,750 m^3/s for the 25-year flood.

A simple numerical hydraulic model with six cross sections within the boundaries of the topographic survey was constructed with a discharge of 2,135 m^3/s, half of the estimated 50-year flood discharge, assuming that the remainder of the discharge would flow to the sea through Río Chapagua or other outlets. The boundary condition was the estimated water-surface elevation of 50-year storm surge (described below) at the first cross section at the mouth of the Río Aguán. The results of this model showed a rise in the water-surface elevation of only 0.08 meter from the first cross section to the last cross section, 2,722 meters upstream.

These model results indicate that there would be little slope of the water surface within the topographic survey boundaries during a flood, and the increased flooding due to the river is minimal compared to flooding caused by the estimated 50-year storm surge.

Hurricanes and Storm Surge

Flooding from storm-surge and waves due to passing hurricanes probably poses a bigger threat to human life and buildings in Santa Rosa de Aguán than flooding from Río Aguán. There is a 6-percent chance in any one hurricane season (June to November) that a hurricane of any magnitude will affect the area within 110 kilometers (60 miles) of Santa Rosa de Aguán and a 2-percent chance in any one hurricane season that a Category 3-5 hurricane will affect the area within 50 kilometers (30 miles) (National Ocean and Atmospheric Administration, 2000a).

Storm surge is ocean water pushed ashore from winds during a storm. During a hurricane, the greatest potential for loss of life is from the storm surge (National Oceanic and Atmospheric Administration, 2002b). The surge can cause storm tides 4-5 feet (1.2–1.5 meters) above normal tide for a Category 1 hurricane, 9-12 feet (2.7–3.7 meters) above the normal tide for Category 3 hurricane, and 18 feet (5.5 meters) above the normal tide for Category 5 hurricanes (National Oceanic and Atmospheric Administration, 1999).

Based on the probability that there is a 2-percent chance (50-year event) that a Category 3 to Category 5 hurricane will affect Santa Rosa de Aguán, the peak water-surface elevation from a 50-year flood due to storm surge can be estimated. An average elevation of the storm-surge range for a Category 3 hurricane is 3.2 meters and the estimated storm surge for a Category 5 hurricane is 5.5 meters. Averaging these two elevations equals a 50-year storm surge of 4.35 meters above normal sea level. To be conservative, it was assumed for the development of the flood-hazard map that the maximum astronomical tide level during the storm surge is the mean higher high water (MHHW) elevation. This elevation is 0.20 meter above the mean lower low water elevation at Puerto Cortes, the nearest tidal gage, located about 325 km due west from Santa Rosa de Aguán (National Oceanic and Atmospheric Administration, 2002c). The predicted tide at Puerto Cortes during the LIDAR survey at Santa Rosa de Aguán was 0.15 meter above the mean lower low tide (National Oceanic and Atmospheric Administration, 2002c). The average of 257 LIDAR-elevation points along a profile extending into the Caribbean Sea was -0.84 meter, therefore the elevation of the MHHW relative to World Geodetic Survey of 1984 (WGS 84) datum, the datum for the LIDAR DEM, is -0.79 meter. Adding the 50-year storm surge elevation, 4.35 meters, to the elevation of the MHHW provides a flood elevation of 3.56 meters (WGS 84). This elevation was used to determine the extent and depth of inundation for the 50-year flood due to storm surge and astronomical tide (figures 3 and 4).

Along with the flooding associated with the storm tide, wave action along the beach can be particularly destructive. Evidence of this destructive power from Hurricane Mitch was evident on the beaches in Santa Rosa de Aguán during a field visit (figure 5). Houses exposed to the wave action were destroyed. Foundations were moved and walls were knocked down. Houses on the landward side of topographic barriers to the open sea were flooded, but had much less structural damage.

The foundation elevations of several houses exhibiting both damaged and relatively undamaged conditions were surveyed by Roberto Gutierrez (University of Texas, written commun., December, 2001) near the beach on the left-bank side of Santa Rosa de Aguán (table 1). All of these houses were exposed to wave action from the storm surge generated by Hurricane Mitch. Although the data are limited, they suggest that the wave action due to the storm surge from Hurricane Mitch caused significant structural damage only below an elevation of 3.0 to 4.0 meters. The importance of a topographic barrier is illustrated in a beach profile of the LIDAR elevation data (figure 6). The foundation of a destroyed house is at a ground elevation of 2.55 meters, but two houses behind a relatively minor topographic barrier are at ground elevations below 2.55 meters, yet were not destroyed (Roberto Gutierrez, University of Texas, written commun., January 2001).

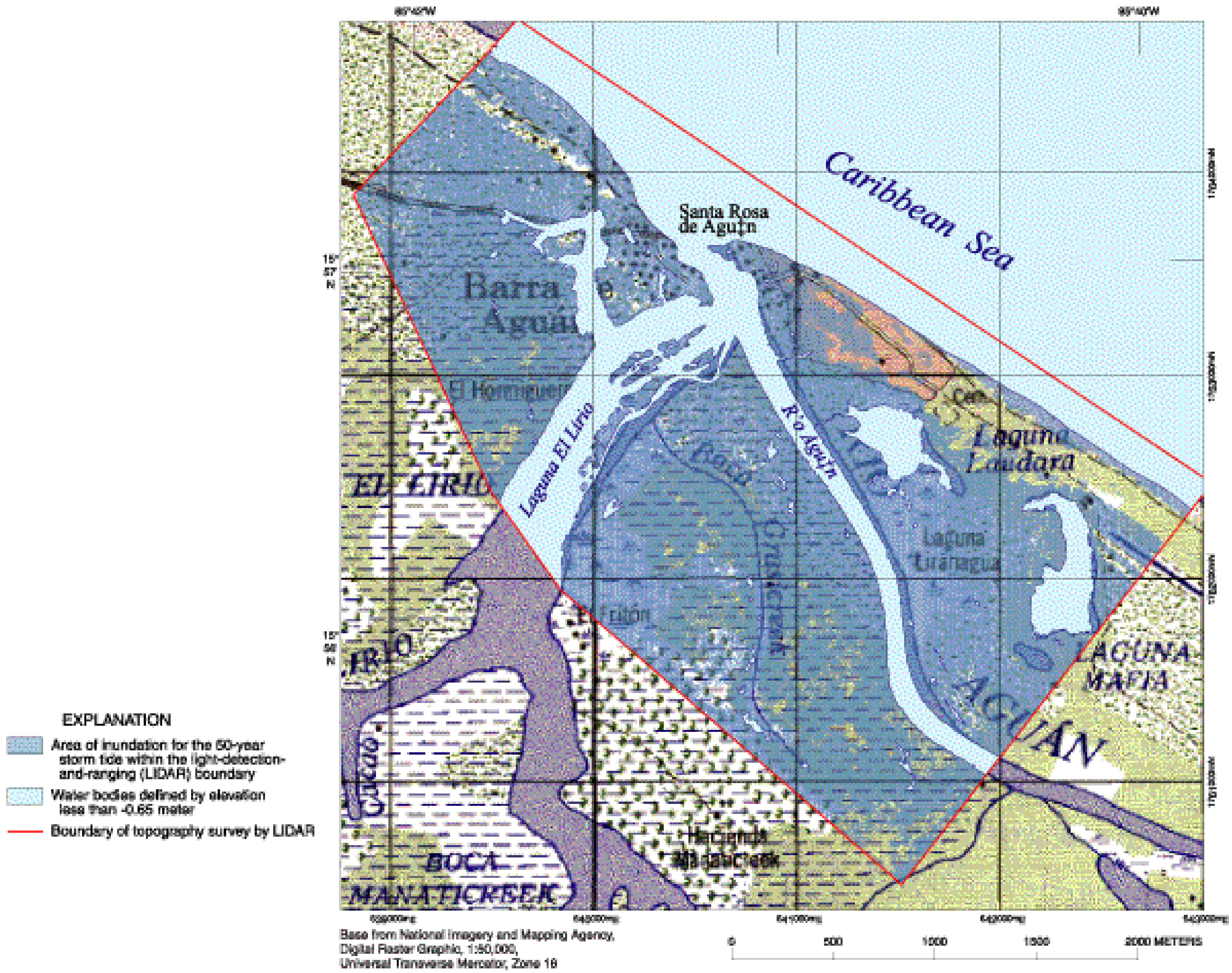

Figure 3. Area of inundation for the 50-year storm tide at Santa Rosa de Aguán, Honduras.

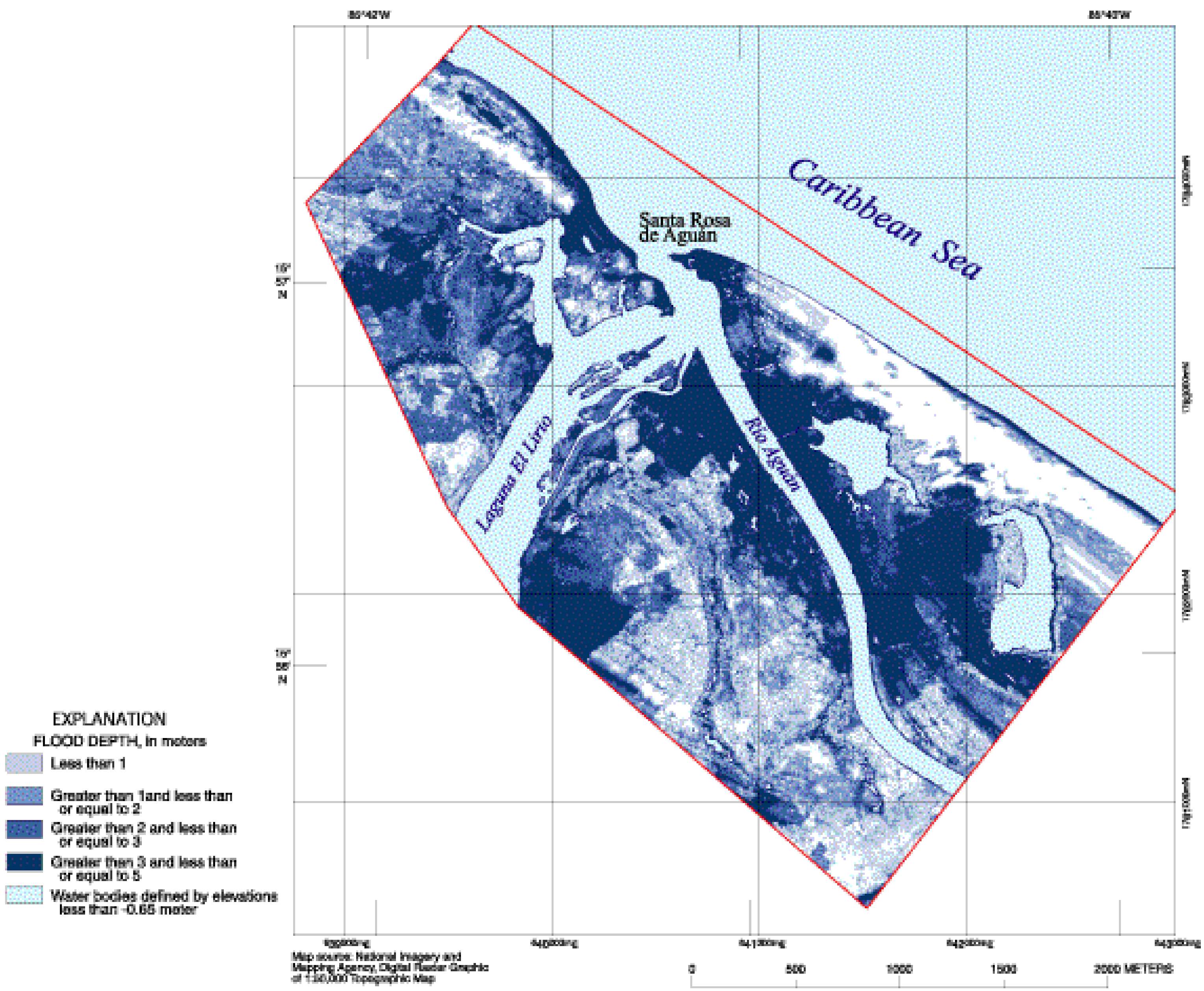

Figure 4. Depth of inundation for the 50-year storm tide at Santa Rosa de Aguán, Honduras.

Figure 5. Houses destroyed by storm-surge wave action at Santa Rosa de Aguán, Honduras, during Hurricane Mitch.

Table 1. Ground-surveyed elevations of house foundations at Santa Rosa de Aguán, Honduras

[**Elevation of foundation**: elevations are referenced to the World Geodetic System Datum of 1984; Average sea-level elevation from the light-detection-and-ranging (LIDAR) survey was -0.84 meters; Source: Roberto Gutierrez, University of Texas, Bureau of Economic Geology, written commun., January 2001]

Status of house	Elevation of foundation (meters)
Destroyed	1.68
Destroyed	2.55
Destroyed	2.18
Destroyed	2.82
Intact	4.09

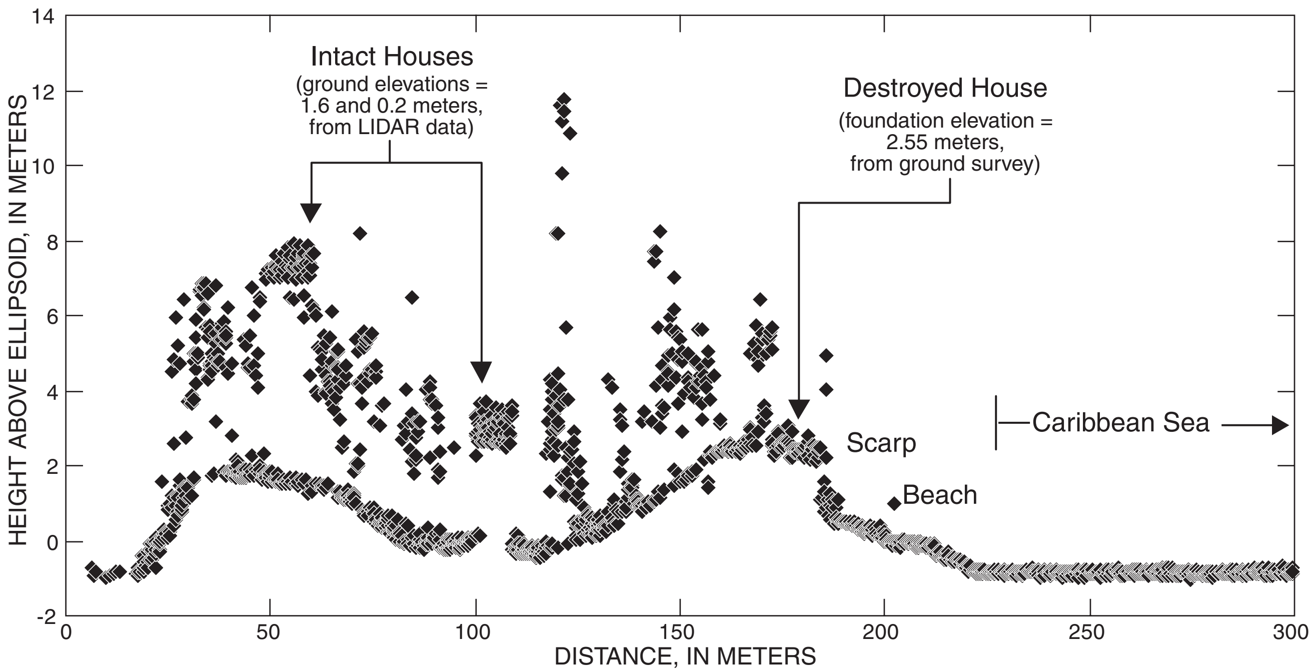

Figure 6. Elevation profile of the beach at Santa Rosa de Aguán, Honduras, from unfiltered light-and-ranging (LIDAR) data showing intact houses behind a topographic barrier and a house destroyed by storm-surge wave action during Hurricane Mitch. (See figure 7 for location of the profile.)

The data for the surveyed houses suggest two factors for the delineation of high-hazard areas that were prone to heavy structural damage due to waves during Hurricane Mitch. The first is the absence or presence of a barrier. Structures situated away from the coastline with a barrier between them and the open sea survived the storm surge with their main structures intact. The second factor is elevation. The waves seemed to affect only exposed structures that had foundations lower than about 3 meters. These two factors were used to delineate the areas of high hazard from waves at Santa Rosa de Aguán, assuming that Hurricane Mitch, rated as a category 1 when it made landfall, is the level of hurricane force or storm surge for a high-hazard rating. First, a boundary was delineated along the ridge line of the coastal berm or highlands parallel to the beach to define the area exposed to waves (figure 7). Where no berm or highland existed near the beach, the boundary was set back because the wave action would extend further inland. Next, within the sea side of this boundary, all land elevations at 3.0 meters or below were designated as areas of high wave hazard (figure 7) subject to destructive wave action during hurricanes.

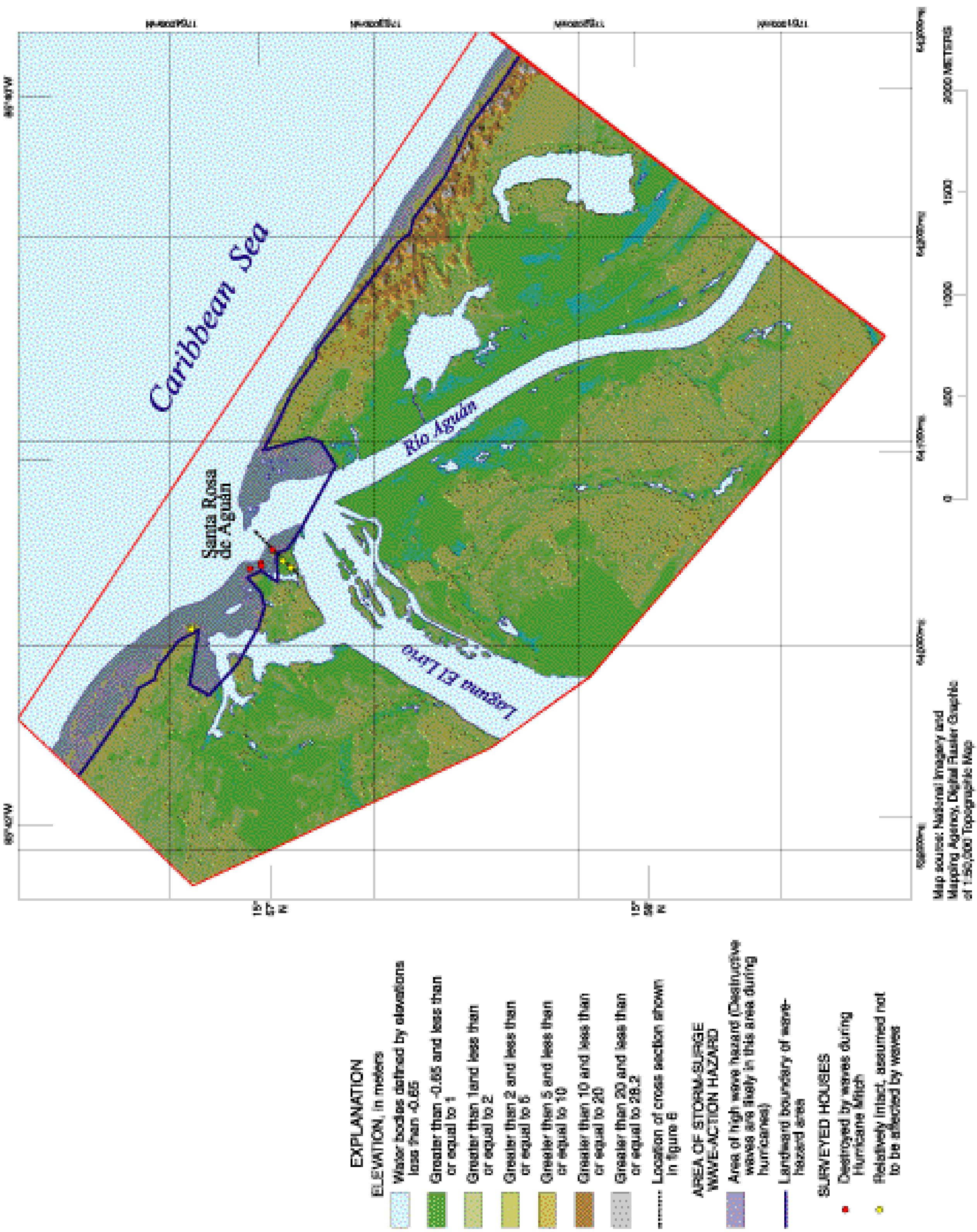

Figure 7. Elevation of the study area and area of storm-surge wave-action hazard at Santa Rosa de Aguán, Honduras.

FIFTY-YEAR FLOOD-INUNDATION MAPS

The GIS coverage of area of inundation was created by intersecting the 50-year storm-tide elevation with the DEM that was produced from the LIDAR data. This coverage was overlain on an existing 1:50,000 topographic digital raster graphics map (figure 3) produced by the National Imagery and Mapping Agency (Gary Fairgrieve, USGS, written commun., 1999). Depth of inundation at Santa Rosa de Aguán for a 50-year-flood (figure 4) was computed by subtracting the 50-year storm-tide elevation from the DEM at grid cells where the area of inundation coverage indicated that flooding would occur to produce a grid with a cell size of 1.5 meters. The color-shaded elevation zones (figure 7) were generated from the LIDAR-derived elevation grid using Arc/Info™ GIS software.

The flood inundation and wave-hazard maps are intended to provide a basic tool for planning or for engineering projects near Río Aguán and along the coastline at Santa Rosa de Aguán. This tool can reasonably separate high-hazard from low-hazard areas to minimize future flooding or wave-action losses. Little of the area shown on figure 3 is completely safe from storm surge or flooding hazards. The ridge paralleling the coast situated next to the beach southeast of the right-bank portion of Santa Rosa de Aguán offers the largest section of land free from storm surge and flooding hazards, but would probably be the most difficult to develop and provide access.

DATA AVAILABILITY

GIS coverages of flood and storm-surge hazards shown on the maps in figures 3, 4, and 7 are available in the Municipal GIS project, a concurrent USAID-sponsored USGS project that will integrate maps, orthorectified aerial photography, and other available natural resource data for a particular municipality into a common geographic database. The GIS project, which is located on a computer in the Santa Rosa de Aguán municipality office, allows users to view the GIS coverages in much more detail than shown on figures 3, 4, and 7. The GIS project will also allow users to overlay other GIS coverages over the flood- and wave-hazard coverages to further facilitate planning and engineering. Additional information about the Municipal GIS project is available on the Internet at the GIS Products Web page (http://mitchnts1.cr.usgs.gov/projects/gis.html), a part of the USGS Hurricane Mitch Program Web site.

The GIS coverages and the HEC-RAS model files for this study are available on the Internet at the Flood Hazard Mapping Data Web page (http://mitchnts1.cr.usgs.gov/projects/floodhazard.html), which is also a part of the USGS Hurricane Mitch Program Web site.

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